The HEMT has become a building block for the microelectronics industry with applications as diverse as radioastronomy and DBS tuners. In a couple of decades it has become a major commercial success story. By no means is that the end of the story. A survey of the research literature reveals a surprisingly wide variety of materials being studied so as to maintain the developing momentum.

Roy Szweda, Associate Editor

The many flavours of HEMT

One of the handful of compound semiconductor success stories in RF devices has been the HEMT. GaAs lends itself well to this device technology and was a worthy successor to the MESFET. It is no surprise then that to extract even more performance out the HEMT, alternative semiconductors must be considered. Such materials include InP, GaN, SiC, InAlAs/InGaAs, antimonides and even silicon.

For instance, GaN high power amplifiers based on HEMTs have been developed for target applications ranging from radar systems to base stations. GaN-based HEMTs could also be extended to mm-wave power applications. They have been demonstrated with power densities over 30 W/mm as well as total output powers of over 170 W. These are useful benchmarks, but reliability has yet to be fully demonstrated and questions remain about how material properties interact with device performance and reliability.

Interestingly, a company that has had great success from AlGaAs HBTs, RF Micro Devices has been investigating epitaxial defects so as to optimise AlGaN/GaN HEMTs. D S Green, *et al*, studied the impact of AlN nucleation conditions on the density and character of threading dislocations on SiC substrates. The HEMT structures were made using flow modulation epitaxy on a custom-built MOCVD reactor.

They found that the variation of the nucleation temperature, V/III ratio, and thickness have a dramatic effect on the balance between edge, screw and mixed character dislocation densities. After RF stress tests, RFMD recorded only a 0.17dBm decrease in the power at peak PAE. They see this as a 'highly encouraging result' which implies that proper device design coupled with managed material imperfections can yield reliable RF devices.

Amongst the many excellent papers at the recent 12th International Conference on MOVPE a French team has reported HEMTs based on GaAlN/GaN heterostructures on SiC: M-A di Forte Poisson *et al*, from Thales Research and Technology/TIGER, the University of Lille, IRCOM-CNRS and IEMN/TIGER. They used LP-MOCVD growth on a range of SiC substrates from different suppliers and assessed their influence on the physical properties of the GaAlN/GaN HEMTs. The static characteristics of the devices, such as Idss or pinch-off voltage, correlate with the nucleation layer composition and with the defect density of the SiC substrate. This optimisation has led to high microwave performance devices, in particular a CW output power up to 4 W/mm at 10 GHz.

Also at this meeting, N Okamotoa, *et al*, from the Nanoelectronics Collaborative Research Centre at the University of Tokyo and Fujitsu Labs Ltd, reported the highest 2DEG mobility (at RT) for InGaN-channel heterostructures using an ultra-thin (3 nm) InGaN-channel.

These experiments used sapphire rather than SiC substrates but the growth regime included a thick GaN buffer layer. Fujitsu reported more benchmark results at the IEDM: a single-chip 101W GaN HEMT power amplifier. In contrast this was fabricated on the relatively lower cost n-type SiC substrate rather than SI SiC or sapphire. Incorporation of an AlN isolating layer enabled M Kanamura *et al*, of Fujitsu to overcome the usual parasitic problems to deliver what could be the kind of cost-effective amplifier the base station market needs. The next step would be to use silicon substrates, but HEMTs on silicon are likely some way off. That said, workers at the University of Michigan have fabricated working III-nitride HEMTs on high resistivity silicon substrates by MBE.

It is appropriate to close this overview with a few words of caution. The HEMT is an attractive subject for R&D but there exist various obstacles which must be overcome before the big market opportunities can be contemplated. Nevertheless, as this short review has hopefully demonstrated, R&D continues and the industry remains hopeful that there will long be a place for the HEMT. Indeed, some have said that the best opportunities for HEMTs are yet to come.